Ceramic Components for Automobile Engines

Introduction

In the face of rising demands upon automobile performance, handling, and efficiency, automobile manufacturers have pursued a wide range of material, manufacturing, and engineering strategies. With the recent passage in the United States of amendments to the Clean Air Act, improvements in engine performance have become a central component of vehicle development programs. While radical innovations in engine technology, such as the two stroke Orbital engine, have been bandied about within the industry, the consensus is that their potential lie in the mid- to long-term. In order to meet performance objectives in the short term, automakers are turning to incremental improvements in existing engine and drivetrain technologies.

One focus of these pursuits has been reduction of the weight of moving parts, particularly reciprocating ones. While weight reduction is an overall plus for vehicle efficiency, the benefits of weight reduction in rapidly moving parts are proportionately much greater than in vehicle structure. The reduction in moving inertia translates into considerable improvements in efficiency.

The engine valvetrain is a natural area for this kind of attention. Engine valves control the delivery of air and fuel to the engine cylinder, as well as the removal of exhaust gases from the cylinder. Furthermore, the way in which the air and fuel blend within the cylinder (governed by the geometry of the valves, cylinder, and other factors) directly effect the way in which combustion takes place, and thus, the efficiency of combustion. Finally, these components must open and close in a fraction of a single engine revolution and, with engines operating at increasingly high RPMs (> 3000), the weight of the components are increasingly important.

Monolithic and fiber-reinforced ceramic materials have been proposed for automobile engine applications for over a decade. Their chemical inertness, thermal properties, inherent strength, and low density have consistently brought them to the attention of engine developers. However, the brittleness of these materials and the technical difficulties associated with forming ceramic components with the necessary small flaw sizes have limited their application. In particular, the only significant application of ceramics in automobile engine components has been in turbocharger rotors, replacing a fairly expensive and high density material, nickel-based superalloys.

Components

In this exercise, we consider three parts: valves, valve guides, and cam rollers. Their characteristics, in both the proposed ceramic systems as well as the conventional steel ones are presented below:

Ceramic Component Performance Specifications

Component	Weight	Material	MTBF*
Valve	0.08 lb (36 g)	Alumina	0.8 x 1.0
Valve Guide	0.031 lb (14 g)	Alumina	0.8 x 1.0
Cam Roller	0.090 lb (41 g)	Alumina	0.8 x 1.0

Steel Component Performance Specifications

Component	Weight	Price	Material	MTBF*
Valve	0.16 lb (73 g)	$1.00	Steel	1.0
Valve Guide	0.062 lb (28 g)	$0.60	Steel	1.0
Cam Roller	0.18 lb (83 g)	$0.75	Steel	1.0

***MTBF** - *Mean time before failure*; a measure of the reliability of the part. The larger this number is, the more reliable (longer lasting) the part is. For the purposes of this case, values are given as the ratio of the MTBF for the ceramic component to that of the steel component.

While you will not need to know a great deal about engine technology to undertake the case, you will need to understand what each of these three parts do in the engine. Refer to Figures 1 and 2 while reading these next sections.

Valves and Valve Guides

Valves are essentially little plungers that open and close either to let air and fuel into the cylinder or to allow exhaust gases to escape the cylinder (see Figure 1). In a conventional Otto cycle automobile engine, the intake valve must open once every two engine revolutions, and the exhaust valve must open once every two engine revolutions. The valve guide is a simple sleeve within which the valve reciprocates, and helps to keep the valve oriented properly.

Automobile engines have traditionally required two valves (and, thus, two valve guides) for each cylinder. Recent developments in the study of engine tribology (combustion and surfaces) have prompted the development of so-called "multi-valve" engines. These engines have two intake valves and two exhaust valves per cylinder, and have seen widespread usage in four cylinder engines. However, six and eight cylinder engines have been moving in this direction as well.

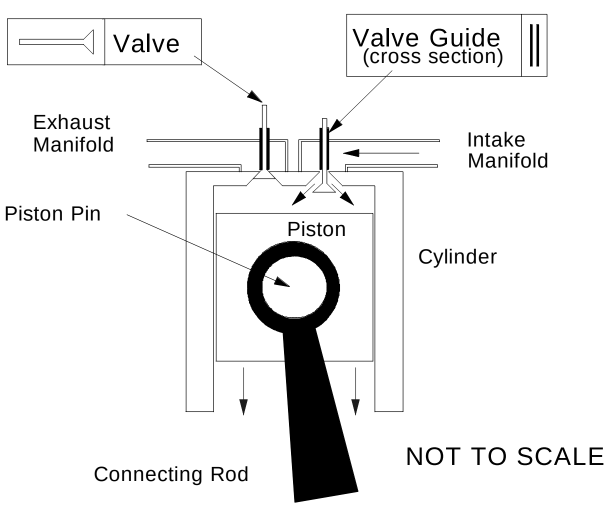


Figure 1: Valves and Valve Guides

For the purposes of the case, you should assume that the mix of multi-valve to dual-valve engines follows the following profile:

	Percentage of Production	
	Multi-valve (4 valves/cylinder)	Dual Valve (2 valves/cylinder)
4 cylinder	75%	25%
6 cylinder	50%	50%
8 cylinder	25%	75%

Cam Roller

The cam roller is a small cylindrical bearing that rides along the surface of the cams (see Figure 2). In order to open and close the valves at the right moment in the Otto cycle, a rotating shaft with eccentrically mounted cams (the camshaft) rotates in coordination with the operation of the engine. As the camshaft rotates, the cams force a mechanical linkage (there are various forms, including tappets, rocker arms, etc.) to move, which themselves force the valves to open and close. The cam roller is a bearing that lowers the wear that the cams undergo. Since the cam roller is part of the mechanism that operates the valve, there must be one cam roller for every valve in the engine.

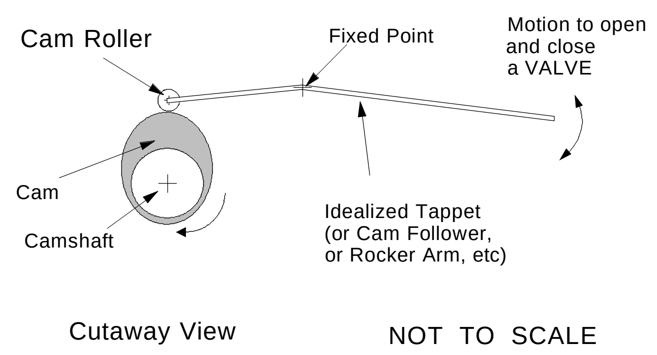
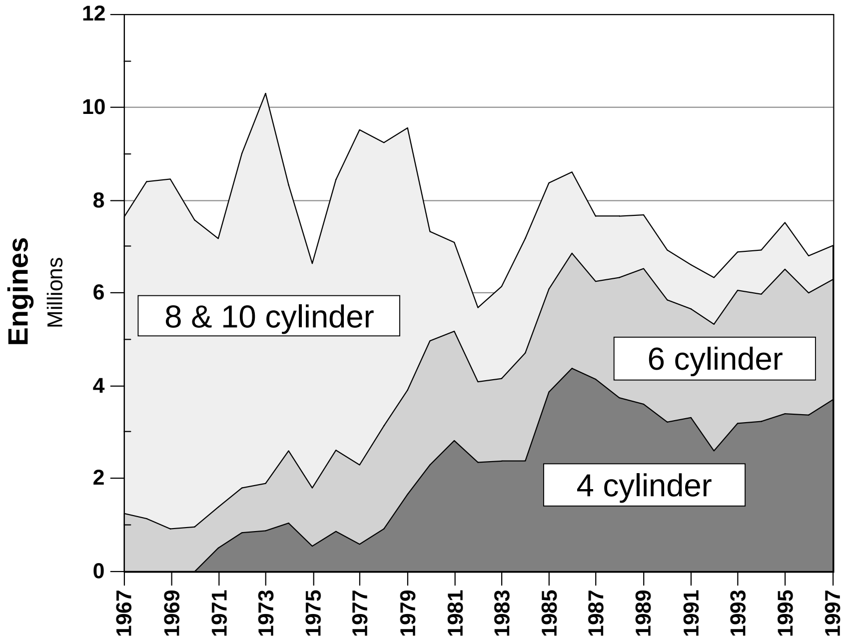


Figure 2: Cam Rollers

Market Predictions

As a part of estimating the relative economics of manufacturing your component, you will have to evaluate your ability to penetrate the market. Your market assessment will necessarily rely upon utility analysis and your assessment of the potential market size.

Market data for the US market is presented in the following graph and table, and an estimate of the ability of ceramics to penetrate this market is tabulated. The market data is taken from various Ward's Automotive reports.



Year	4-cyl	6-cyl	V-8	Total
1967	600	1,257,000	6,401,000	7,658,600
1968	1,000	1,150,000	7,248,000	8,399,000
1969	6,100	931,400	7,539,200	8,476,700
1970	2,300	974,000	6,610,000	7,586,300
1971	520,000	880,000	5,781,000	7,181,000
1972	851,800	970,100	7,201,000	9,022,900
1973	887,900	1,023,700	8,398,700	10,310,300
1974	1,058,800	1,558,800	5,719,100	8,336,700
1975	565,443	1,254,158	4,828,081	6,647,682
1976	869,266	1,762,965	5,813,129	8,445,360
1977	599,724	1,708,767	7,215,572	9,524,063
1978	939,611	2,211,509	6,102,612	9,253,732
1979	1,664,756	2,262,087	5,641,420	9,568,263
1980	2,308,556	2,682,626	2,358,547	7,349,729
1981	2,827,622	2,358,025	1,909,211	7,094,858
1982	2,362,081	1,733,692	1,614,348	5,710,121
1983	2,382,274	1,793,980	1,982,252	6,158,506
1984	2,382,274	2,338,228	2,448,437	7,168,939
1985	3,888,594	2,199,929	2,296,215	8,384,738
1986	4,396,511	2,465,936	1,758,645	8,621,092
1987	4,152,325	2,100,097	1,417,449	7,669,871
1988	3,750,910	2,591,791	1,325,452	7,668,153
1989	3,613,461	2,921,522	1,153,232	7,688,215
1990	3,227,157	2,638,512	1,059,560	6,925,229
1991	3,327,213	2,312,925	887,086	6,528,224
1992	2,766,036	2,587,659	953,002	6,306,697
1993	3,174,548	2,875,327	812,674	6,862,549
1994	3,254,315	2,733,903	950,621	6,938,839
1995	3,405,961	3,112,733	999,984	7,518,678
1996	3,384,780	2,628,823	796,820	6,810,423
1997	3,718,840	2,572,960	738,144	7,029,944

For the purposes of the case study, you should assume that the number of engines sold in each class remains the same between now and your planning horizon. You can make your own assessments beyond this time period. While all of the components will be introduced to the market next year, the number of engines that will convert from steel to ceramic will be uncertain. Experts who have studied the market for these three components have developed the following potential market development scenarios. Remember that the likelihood of each of these scenarios will depend upon the relative utility of the steel component and the ceramic alternative.

Market Share Estimates

Component		**Low**	**Average**	**High**
Valve & Valve Guide	1995	1%	5%	10%
	2000	3%	10%	20%
	2005	5%	15%	35%
Cam Roller	1995	2%	5%	7%
	2000	5%	10%	13%
	2005	7%	15%	20%